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Laboratory astrophysics and atomic physics using the NASA/GSFC microcalorimeter spectrometers at the LLNL electron beam ion trap and radiation properties facility

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Abstract

The 32 pixel laboratory microcalorimeter spectrometer built by the NASA/Goddard Space Flight Center (GSFC) is now an integral part of the spectroscopy suite used routinely by the electron beam ion trap and radiative properties group at the Lawrence Livermore National Laboratory. The second generation laboratory instrument, dubbed the XRS/EBIT, is nearly identical to the XRS instrument on the *Suzaku* X-ray Observatory, formerly Astro-E2. The detector array is from the same processed wafer and uses the same HgTe absorbers. It is being used to measure the photon emission from a variety of radiation sources. These include X-ray emission from laboratory simulated celestial sources, X-ray emission from highly charged ions of Au, and X-ray emission following charge exchange and radiative electron capture. The wide range of applications demonstrates the versatility of a high-resolution, high-efficiency low-temperature detector that is able to collect data continually with minimal operator servicing.

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1. Introduction

Microcalorimeter arrays built by the NASA/GSFC have operated at the Lawrence Livermore National Laboratory since the year 2000. The first was a 6×6 array with approximately 10–12 eV resolution, the second and currently operational microcalorimeter, dubbed the XRS/EBIT, is a 6×6 array with ~6–7 eV resolution at 6.7 keV. The XRS/EBIT has become an integral part of the suite of spectrometers in operation at the LLNL EBIT facility that also includes high-resolution grating and crystal spectrometers, and high-efficiency solid state detectors. It has been used for a variety of studies of X-ray emission from highly charged ions. These studies have been dominated by laboratory astrophysics measurements, i.e., measurements of absolute excitation cross-sections of Fe L-shell transitions and of the X-ray emission following charge exchange recombination between ions found in the solar wind and neutral material found in cometary atmospheres. The utility of the XRS/EBIT has now expanded to include studies of other basic atomic parameters such as atomic lifetimes as well as studies of X-ray emission from highly charged high-Z material, such as Au^{43+} and Au^{69+}. Here, we will give a synopsis of some of these studies, and a brief discussion of the XRS/EBIT microcalorimeter array.

The LLNL EBIT-I is used to create, ionize, and trap highly charged ions. It is able to make highly charged ions

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of all the astrophysically relevant elements under well-controlled conditions. In addition, EBIT-I can be run in the magnetic trapping mode, where the electron beam is turned off and the ions are trapped by the strong magnetic field of the superconducting Helmholtz coils and the electric potential of the drift tube assembly. We use this mode to measure the X-ray emission from charge exchange recombination (CEX). EBIT-I has six radial ports that grant access to the trap region. The XRS/EBIT views the trapped ions and records their X-ray emission through one of these six ports. The remaining ports are employed by a gas injector, a laser injection system, and by grating, crystal, and solid state spectrometers. For a review of the LLNL EBIT facility see Ref. [1].

The XRS/EBIT consists of a 28 $624 \times 624\,\mu m^2$ HgTe absorbers and four Bi absorbers, each mounted on a monolithic silicon thermistor and arranged in a 6×6 array. The Bi absorbers are used for high-energy photon absorption. The HgTe absorbers are used for both high-energy and low-energy photon absorption. The HgTe absorbers are the same as those on the XRS microcalorimeter on the *Suzaku* X-ray observatory, and the silicon thermistor array was made from the same wafer as the *Suzaku* XRS. The XRS/EBIT is, therefore, a near replica of the flight XRS. Fig. 1 shows the X-ray emission from helium-like Fe XXV and hydrogenic Fe XXVI emitted from the LLNL EBIT-I and measured with the XRS/EBIT. A full description of the instrument can be found in Porter et al. [2].

For most of the time the XRS/EBIT has operated, the detected pulses have been processed using either a *Suzaku* flight spare calorimeter digital processor (CDP) or the engineering model CDP. The flight spare CDP has 32 independent processors, one for each pixel [3]. The engineering model has only 16 processors and, hence, could only support half the array. It was used at EBIT-I while the flight spare CDP was employed for testing of the *Suzaku* XRS. Recently, the pulse processing has been changed to a software calorimeter digital processor. Like the hardware version, the software performs real time processing of the pulses from all 32 pixels.

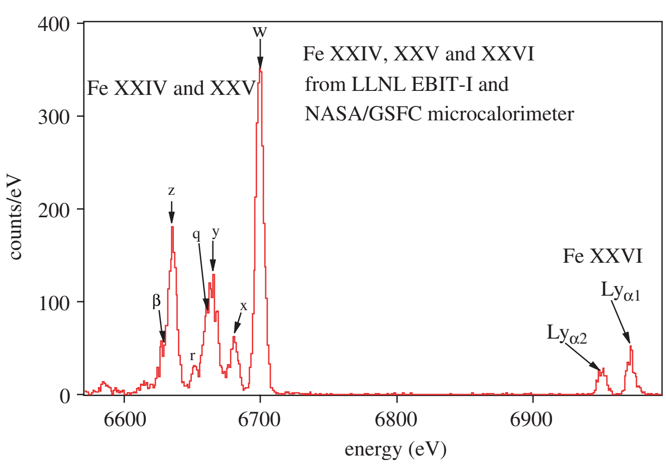

Fig. 1. Spectrum of helium-like Fe XXIV and hydrogenic Fe XXV measured with the XRS/EBIT. The resolution is 6.5 eV for 14 summed channels. This measurement was taken prior to the installation of the software calorimeter digital processor (SCDP). Using the SCDP, all 32 channels operated simultaneously once again.

2. Laboratory measurements

Because it is a non-dispersive spectrometer and has a high collection area, the XRS/EBIT is well suited for measuring X-ray emission following charge exchange recombination (CEX) between highly charged ions and neutral material. The $\leqslant 7\,eV$ resolution of the XRS/EBIT provides stark improvements in the quality of X-ray spectra measured from CEX at EBIT-I compared to solid state detectors used in previous EBIT experiments or CCDs employed to measure X-ray emission from comets. Using the EBIT-I's magnetic trapping mode, where the source of X-ray emission is no longer restricted to the narrow electron beam, we have measured X-ray spectra of CEX between low-Z bare and hydrogenic ions found in the solar wind and neutral gas found in cometary atmospheres (see Fig. 2). These data are being used to fit X-ray spectra from comets [4]. In the near future, we plan to measure CEX X-ray emission from reaction between higher Z materials, namely bare Fe XXVII, and atomic hydrogen.

One largely untested parameter found in spectral models used to interpret X-ray spectra from celestial sources is the excitation cross-section. Since the XRS/EBIT has been at LLNL we have measured the absolute cross-sections of many of the strongest Fe L-shell lines from Fe XVII–Fe XXIV. Our measurements are completed by normalizing to the well-known cross-sections of radiative recombination. Because of the XRS/EBIT's $\leqslant 10\,eV$ resolution, long time gain stability, and large collection area, it is possible to detect the weak (~1000 times weaker than direct excitation)

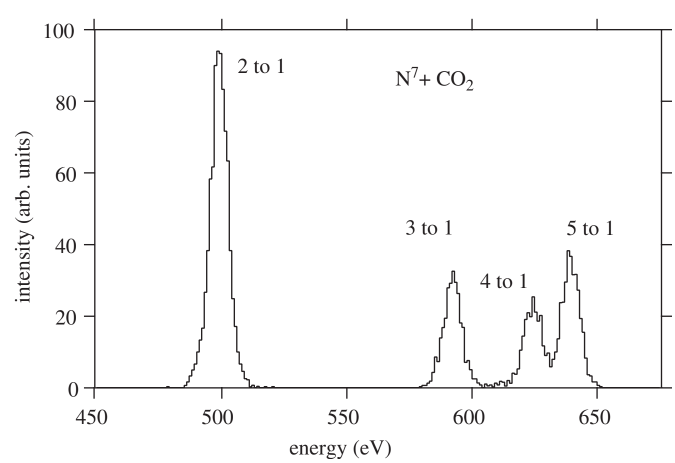

Fig. 2. Spectrum of X-ray emission following the low-energy charge exchange between bare nitrogen 7+ and CO_2. Notice the distinct spectral signature given by the strong $n \geqslant 3 \rightarrow 1$. For more details see Ref. [4].

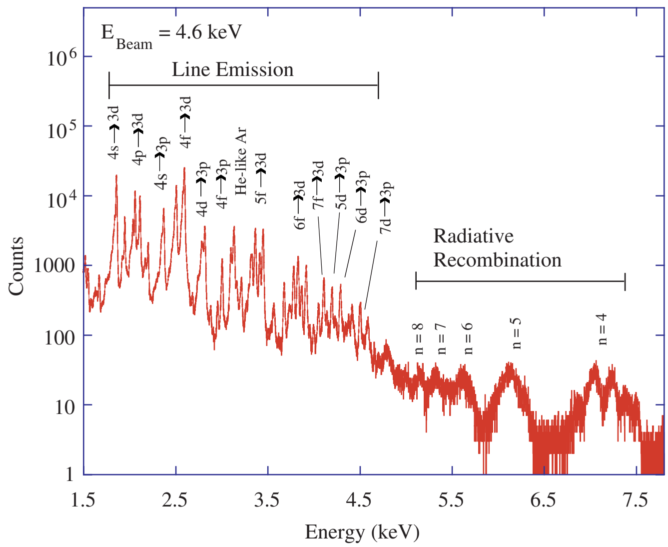

Fig. 3. Gold M-shell spectrum measured at a beam energy of 4.54 keV. This figure is from Ref. [9].

RR emission and resolve RR features from different ions. Results from absolute excitation cross-section measurements for Fe L-shell transitions can be found in Refs. [5,6]

X-ray emission from M-shell and L-shell transitions in Au^{43+} through Au^{69+} is complex and accurate transition energies and intensities are difficult to calculate. We have used the XRS/EBIT at the LLNL EBIT-I to measure and identify the X-ray emission from L-shell and M-shell transitions in highly charged gold ions. In addition, accurate charge balance is determined from the RR emission which is measured simultaneously owing to the large bandwidth of the XRS/EBIT (see Fig. 3). These data are being used to test models and design diagnostics for indirect drive inertial confinement fusion experiments. Results can be found in Refs. [7–9].

The XRS/EBIT continues to be a useful instrument at the LLNL EBIT facility. In the near future, the refrigerator system will be upgraded to reduce the operator service and increase the data acquisition efficiency.

Acknowledgements

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